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# Advanced Space System Concepts and Their Orbital Support Needs (1980—2000)

## Volume I: Executive Summary

(Study of the Commonality of Space Vehicle Applications  
to Future National Needs)

(UNCLASSIFIED VERSION)

Prepared by:

I. BEKEY, H. L. MAYER, and M. G. WOLFE  
Advanced Mission Analysis Directorate  
Advanced Orbital Systems Division

April 1976

Prepared for:

OFFICE OF SPACE FLIGHT  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
Washington, D.C.

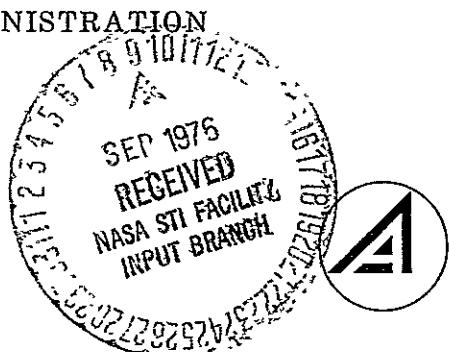
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Systems Engineering Operations  
THE AEROSPACE CORPORATION

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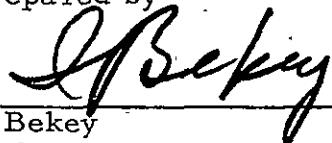
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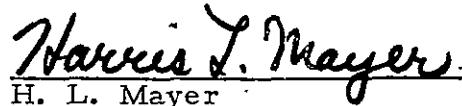
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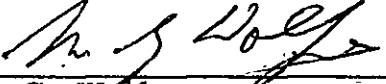


I. Bekey  
Study Director  
Advanced Mission Analysis Directorate  
Advanced Orbital Systems Division



H. L. Mayer

Principal Staff Scientist  
Advanced Programs Division



M. G. Wolfe  
Staff Engineer  
Advanced Mission Analysis Directorate  
Advanced Orbital Systems Division

Approved



R. H. Herndon  
Group Director  
Advanced Mission Analysis Directorate  
Advanced Orbital Systems Division



Samuel M. Tennant  
General Manager  
Advanced Orbital Systems Division  
Systems Engineering Operations

## FOREWORD

This report documents the results of Study 2.5, "Study of the Commonality of Space Vehicle Applications to Future National Needs," performed under NASA Contract NASW 2727, during Fiscal Years 1975 and 1976. Capt. R. F. Freitag and Mr. F. S. Roberts, Advanced Programs, Office of Space Flight, NASA Headquarters, provided technical direction during the course of the effort. The report is being issued in separate classified and unclassified versions.

The report is comprised of four separate volumes entitled:

Volume I: Executive Summary

Volume II: Final Report

Volume III: Detailed Data - Part I: Catalog of Initiatives, Functional Options; and Future Environments and Goals

Volume IV: Detailed Data - Part II: Program Plans and Common Support Needs

The first two volumes summarize the overall report. The third volume presents a catalog of the initiatives and functional system options; and thoughts on future environments and needs. The fourth volume matches the "initiatives" against the requirements and presents detailed data on alternate program plans for alternate future scenarios, from which likely supporting vehicle and technology needs are derived.

## ACKNOWLEDGMENTS

The study was performed for NASA under the direction of Mr. I. Bekey, Study Director and Assistant Group Director of the Advanced Mission Analysis Directorate.

The bulk of the innovative technological material was prepared by I. Bekey and Dr. H. Mayer jointly in a collaborative team effort. The material dealing with the future environments and goals was prepared primarily by Dr. H. Mayer. The programmatic material was prepared by Dr. M. Wolfe and I. Bekey jointly. The marshalling of other Aerospace Corporation resources including system weights estimation was performed by Dr. M. Wolfe. Cost estimation was aided by Mr. H. Campbell. The program evaluation algorithm and the extent of the spectrum of alternate world scenarios were provided by Dr. G. V. Nolde, consultant. Mrs. Janet Antrim provided invaluable and patient support in copy preparation and manuscript typing. The dedicated efforts of all participants are hereby gratefully acknowledged.

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## 1. INTRODUCTION

### 1.1 OBJECTIVES

The objectives of the study were to determine the likely system concepts which might be representative of NASA and DoD space programs in the 1980-2000 time period, and to determine the programs' likely needs for major space transportation vehicles, orbital support vehicles, and technology developments which could be shared by the military and civilian space establishments in that time period. Such needs could then be used by NASA as an input in determining the nature of its long-range development plan.

### 1.2 STUDY APPROACH

The approach used in this study was to develop a list of possible space system concepts ("initiatives") in parallel with a list of needs based on consideration of the likely environments and goals of the future. The two lists thus obtained represented what could be done, regardless of need; and what should be done, regardless of capability, respectively. A set of development program plans for space application concepts was then assembled, matching needs against capabilities, and the requirements of the space concepts for support vehicles, transportation, and technology were extracted. The process was pursued in parallel for likely military and civilian programs, and the common support needs thus identified. The approach is illustrated in Figure 1-1.

### 1.3 GROUND RULES

The time period covered in the investigation began in 1980, as it was unlikely that significant impact could be made on any program prior to that date; and concluded on or about the year 2000, since it was not likely that meaningful technology or need forecasts much beyond that date could be made.

Constraints due to current projected budgets, policies, treaties, and national goals were considered not necessarily valid in the process of

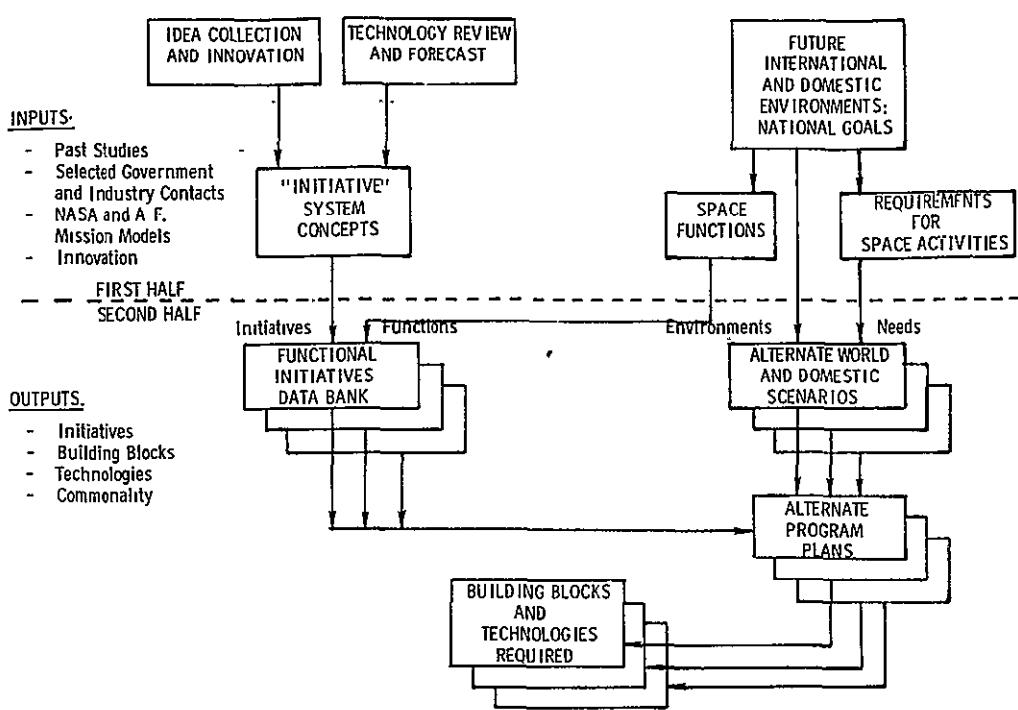


Figure 1-1. Study Approach

synthesis of the system concepts and program plans in order to allow for treatment of alternate futures and consideration of all options.

All technology advances that appeared possible (in areas in which the requisite phenomena had already been identified) were considered to be feasible in this study. Bold technology forecasts were encouraged; thus limitations due to the current funding of technology projects or number of skilled workers currently available in any one field were not considered valid for a 25-year projection. It was assumed that an overriding need for a space capability would result in appropriate budget and priority allocations, would result in training of the necessary work force if needed, and would create extremely rapid progress compared to current rates in most cases.

#### 1.4 SOURCES

The study team gathered data for inclusion in the environment and system concepts portions of the work from past NASA and DoD planning

studies, current NASA and Air Force mission models, and discussions with some key people in government, industry, and science. However, the bulk of the innovative system concepts and the perspectives on utilization of space were developed by the study team during the course of the study. The data in this report was developed independently from the NASA "Outlook for Space" Study, which ran concurrently.

#### 1.5 NO ADVOCACY OR ENDORSEMENT

Though the starting points of the program planning in this study were the current and programmed space projects, the projection of future capabilities and needs was performed by the authors without official input by any element of the NASA or DoD. Furthermore, even though some of the material presented may well be reasonably representative of actual NASA or DoD planning, no official or unofficial NASA or DoD endorsement is implied of the material contained herein. The thoughts are solely the views of the authors.

The system concepts and their technological base are presented with no evaluation of the relative merits of space versus terrestrial approaches, and indeed, no value judgment that any one concept or group of concepts is "better" than any other. None of the individual system concepts shown herein are advocated *per se*, as they are intended to serve as examples of what could be done, and may well vary from other embodiments of similar principles in significant detail or numbers. However, the perspectives of space application and insights on how to operate in space through the close of this century, as well as the serious consideration of the collective space capabilities of some group of space system concepts (such as the ones identified herein) is recommended by the authors.

## 2. CONCLUSIONS

This study provided several major insights, which are reviewed in this chapter.

### 2.1 TECHNOLOGY

Whereas in the past, technology did not permit the performance of many functions in space, the technology both available now and forecasted to be capable of being developed in the 1980-2000 time period will enable the performance of almost any function imaginable. Particularly high leverage was found in large antennas and optics, high prime and transmitted energy, lasers, microelectronic processors and sensor focal planes, and cryogenic refrigerators.

### 2.2 INITIATIVE SYSTEM CONCEPTS

The high leverage technology will allow the fielding of a large number of variety of system concepts, with over 100 such initiatives having been identified in this study. While none are advocated per se, the set identified, as well as many other sets possible, utilize a number of unifying principles applicable to guide the development and operation of space systems for the rest of this century.

These principles include extending the benefits of space services to very many, very tiny, cheap, simple, and personal user sets by deliberately making the satellites large and complex, even if they become heavy and expensive as a result. (The cost of the user equipment, as well as the sum of the user and satellite equipment are minimized, while performing functions not otherwise possible); use of passive reflectors for routing energy generated on the ground or in space; use of space for the gathering, processing, and dissemination of information; combination of functions into multifunctional satellites; and others.

The application of these principles will allow space to become useful and relevant in the everyday lives of large numbers of average citizens,

provide a great range of services to industry and all levels of government, provide an economic incentive for investment by capital in the return implicit in the user charges for those services, and support sophisticated programs of science, exploration, and the advancement of knowledge. Space could also materially affect the balance of power in Defense applications, the details of which are treated in the classified version of this report.

The initiatives identified fall into different risk and time-frame classes varying from low-risk applications of today's technology in the early 1980 period to identification of concepts requiring great advances in technology not likely until the end of the century, and possibly posing some hazards associated with their operation.

Technology programs were also identified which will protect the options to develop most of the identified or likely initiatives, without requiring great expense or commitment to any such initiative.

### 2.3        ORBITAL TRANSPORTATION AND SUPPORT

The large and complex spacecraft identified will require assembly, initialization, servicing, and modification in orbit in order to be feasible, economically attractive, or both. Accordingly, orbital transportation vehicles and orbital supporting facilities have been identified which could meet the needs anticipated for both NASA and DoD in the time period, and which are likely to be needed regardless of the exact nature of the future world. Six alternate world futures were examined in this study toward that end, and these conclusions generalized to other world futures as well.

Many mission opportunities were found to exist for the Space Shuttle, which was found to be an exceedingly useful low-orbit launch vehicle, as well as some opportunities for much larger reusable lift vehicles and some expendable ones. Many mission opportunities were likewise found to exist for orbital transfer vehicles including the Interim Upper Stage, Full Capability Tug; a much larger tug with a manned capsule, and a Solar Electric Propulsion Stage. Many opportunities were also found for the application of manned and/or unmanned vehicles or facilities for fabrication, assembly, initialization, servicing, and modification of spacecraft.

Development plans for such facilities were identified which would probably be able to support most initiative concepts identified in this study, or likely to be identified in the near future, regardless of their exact characteristics. The degree of common need for such transportation and support vehicles and facilities by the postulated military and civilian programs in the 1980-2000 time period was found to be high for most of the more moderate views of the future. It seems likely that one set of vehicles and facilities could support both NASA and the DoD.

#### 2.4 ROLES OF MAN IN SPACE

This study did not attempt to address differences (or similarities) and advantages (or disadvantages) of manned versus unmanned space operations. While no initiative was identified which would be impossible to orbit and operate without man in space, many of the larger initiatives could well become economically attractive only by large scale use of man in space. In this light, whereas past justification for man's participation in the space program tended to emphasize exploration, research, and science, a very practical application-oriented case could be made for man's participation in space in the next 25 years. Since many of the initiatives and system concepts identified will require assembly on orbit, servicing, initialization, and reconfiguration of large, very complicated structures, assemblies, or groups of assemblies, man's primary role could be viewed as that of performing such functions (though tradeoffs between manned versus automated approaches clearly must be performed). Whether such functions are performed by hand in EVA or using teleoperator devices operated from space, man will of course need life-support facilities, "yards" and "warehouses" for assembly and servicing, research and test stations, etc. Thus, a progression of increasingly capable "space stations" might be needed, which are viewed as supporting facilities for a working force to assemble and keep operating the groups of satellites which perform earth-oriented services (which are in themselves accepted in terms of their contributions to life on earth). Viewed in this light, a manned space program may take on a vitality not possible otherwise.

## 2.5        BUDGETS

The programmatic information developed in this study indicates that the budgets required to develop, orbit, and operate the civilian initiatives identified (including those conceived during the course of the study, gathered from other studies and sources, and those in the 1973 NASA Mission Model, which is about 120 programs all told) is estimated to be less than five billion 1975 dollars per year averaged through the year 2000. Similarly, less than ten billion 1975 dollars per year averaged through the year 2000 would be required for both civilian and military programs for most non-catastrophic futures. This assumes, of course, that the funding peaks can be either properly phased or amortized into the total time period, and may call for some imaginative arrangement with the financial community to absorb the peak demands and be paid back during the more slack times. Enormous increases in services provided by space can thus result from slightly more than doubling the budget of the space program.

## 2.6        PUBLIC EDUCATION

The general public is not aware of the possibilities which space has for influencing their daily lives (nor is a fair fraction of the space community for that matter). It is vital that the perspectives of space operation, and the types of services the resulting space system initiatives could provide, be exposed within the technical community and to the public at large. The long-range goals for the space program should be selected, and budgets requested for its support, so that a program of balanced national priorities can evolve. The education of the public and its representatives in government is seen as a vital step toward ensuring that the space program is allocated appropriate attention and an appropriate share of the national budget.

### 3. GUIDING PRINCIPLES FOR SPACE UTILIZATION

This section provides some insights into principles which should be used to guide space utilization for the rest of this century. These principles were derived from past experience in the application of space programs, an overview of the group of initiative concepts is presented in Section 5, and feedback from presentation of the material to key people. The discussion is summarized in Table 3-1.

Table 3-1. Guiding Principles for Space Utilization

GENERAL

1. Exploit the large geometrical coverage.
2. Exploit the benign environment (except for the radiation belt altitudes).
3. Exploit the excellent transmission of energy and information.

APPLICATIONS

1. Extend utility of space to very many tiny, cheap, simple personal user sets by making satellites large, heavy, and complex.
2. Use passive reflectors in space for routing and directing information and energy over large ground distances. The sources and users can be on the ground, in the air, or in space.
3. Geostationary and other high altitude orbits best serve most domestic and some international applications, including large-scale observation, communications, energy delivery, tracking and control, readout and monitoring, and other applications in which constant coverage is desirable.
4. Low altitude multiple satellites best serve most applications where many widely separated nations wish to benefit from the same satellite and where intermittent contact is permissible, and applications where satellite proliferation is an aid in function.
5. In the far term, evolve the above operation functions into multi-functional satellites, some in low and some in high altitude orbits.
6. High value satellites may have to be protected.

SUPPORT

1. Assemble large and/or massive structures in orbit instead of lifting the entire structure on very heavy lift boosters. Fabricate low density structures in orbit to maximize utility of booster payload volume.
2. Service and repair satellites to allow simple, crude, inexpensive design and to extend useful life.
3. Build two classes of orbit-to-orbit transfer vehicles: slow but efficient unmanned stages with payload capacities into geostationary orbit equal to that of the Shuttle, and fast transfer manned vehicles to minimize radiation exposure.
4. In orbit, energy is free but mass expensive, having been lifted from the earth. Therefore, collect and reuse orbital mass whose function has been expended.
5. Consider primary roles for man to be assembly, initialization, repair, modification, and retirement of complex satellites, in addition to research, exploration, and command.
6. In the far term, evolve the support functions (assembly yards, warehouses, factories, research labs) into integrated orbital support facilities - some in low orbit, some in high orbit. Furnish mass, information, and energy to all satellites from such support bases.

#### 4. ADVANCED TECHNOLOGY

Advanced technology is the key to being able to perform more functions for more people from space. This technology is briefly reviewed in this section.

##### 4.1 HIGH LEVERAGE AREAS

Almost all areas of technology will contribute to the future of the space program, although there are some areas which on consideration will have the highest leverage in enabling the construction of many types of space concepts with a great range of potential utility. These areas have been listed in Table 4-1.

Table 4-1. Technology Developments with High Potential  
for Space Applications 1980-2000

###### EXPLOITED IN STUDY

1. LARGE STRUCTURES OR ARRAYS IN SPACE
2. HIGH POWER, ENERGY
3. LASERS
4. ADVANCED COMPUTERS, ANALOG PARALLEL PROCESSORS
5. CHARGE-COUPLED-DEVICE SENSORS
6. LONG-LIFE CRYOGENIC REFRIGERATORS

###### NOT EXPLOITED IN STUDY BUT WORTHY OF CONSIDERATION

1. RADIATION ENGINEERING AT FREQUENCIES BETWEEN THE INFRARED AND MICROWAVE REGIONS
2. PLASMA PHYSICS APPLICATIONS
3. LASER-FUSION PROPULSION
4. COLLECTIVE MODE PARTICLE-ACCELERATORS
5. EXTREMELY LOW TEMPERATURE SOLID STATE PHENOMENA
6. HIGH INTENSITY SHORT PULSE MAGNETIC FIELDS
7. SURFACE CHEMISTRY
8. BIOLOGY

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The first category of items identified will allow communications with tiny transmitters from far away; the sensing of weak phenomena; attainment of high resolution both spatially and spectrally; the generation and transmission of energy over large distances with low capture losses and great selection over interfering sources; observation over large solid angles with high frequency of coverage and simultaneous high resolution; observation in many spectral regions including the far infrared; and the computation and processing of almost all data in space, resulting in low data link rates to the ground and an increase in sophistication of space operations. The potential of many of these advanced technology areas will only be fully realized if space assembly and servicing is practiced routinely. Additionally, the role of man may well be fundamental in some advanced applications of space technology, whether as on-line operator or in supporting roles.

The second category of technology items identified pertains to those recognized as having great potential but not exploited in this study for synthesis of systems concepts due to insufficient knowledge of the phenomenology. These items are shown in the lower half of Table 4-1.

#### 4.2 TECHNOLOGY PROJECTIONS

Quantitative technology projections were made in the areas of large microwave antennas, large optics, and information processing. The use of assembly, initialization, and servicing in space, together with large payload reusable transportation stages, will result in the ability to build antennas whose diameter is measured in miles, and optics measured in thousands of feet, with dramatic increase in capability compared to today's devices.

##### a. Antennas

Large multibeam antennas will allow large-scale frequency reuse while servicing portable communications terminals with slot or stub antennas suitable for wrist radio applications. Large-phased arrays will generate very narrow electronically steerable beams for radar, energy transmission, and other space-selective uses. Passive reflectors and diffractors will allow space to direct energy originated on the ground, or in space, with simple

structures. Thin film and advanced composite structural materials will be used extensively to attain a weight per unit projected area of 0.01 lb/ft<sup>2</sup> for passive reflectors to 6 lb/ft<sup>2</sup> for multibeam lens antennas.

The very large antennas discussed above could be constructed as one large space structure, stiff enough to assure coherent performance, or alternately using a technique which has been conceived at The Aerospace Corporation under this contract. In this technique, illustrated in Figure 4-1, a number of small sub-arrays or sub-elements of the antenna, with total area about equal to that of a single structure but consisting of smaller dishes, individual dipoles, or collections of dipoles, would be coarsely stationkept with respect to each other and to one or more central sensing and control units, also stationkept in the vicinity. Small laser radars aboard the control units would measure the position of each element to an accuracy of a small fraction of the RF wavelength being used, and then adaptively command the phase of the feed in each sub-array to cause in-phase reception or in-phase generation of energy by the elements of the array. The laser command units would also measure or derive velocity and attitude of the elements and issue commands for controlled stationkeeping. Indeed, with sufficiently precise measurement and control, the accuracy of stationkeeping may be such as to preclude the need for phase control. Using the elements of such a technique, space antenna arrays measuring many miles across should be as feasible as much smaller ones incorporating only a few elements.

The sensing units could alternatively sense phase information directly, be in the near vicinity or on the earth, or be single or multiple for triangulation. Very dense as well as highly thinned antenna arrays should be possible, consisting of identical modular elements, and comprising antenna arrays of arbitrary size in space. In basic terms, physical webs would be replaced with information webs, which should result in lighter weight antennas and contribute to basic feasibility of construction in very large sizes. Antennas constructed in such an "adaptive array" fashion are utilized heavily in synthesis of the initiatives of Section 5.

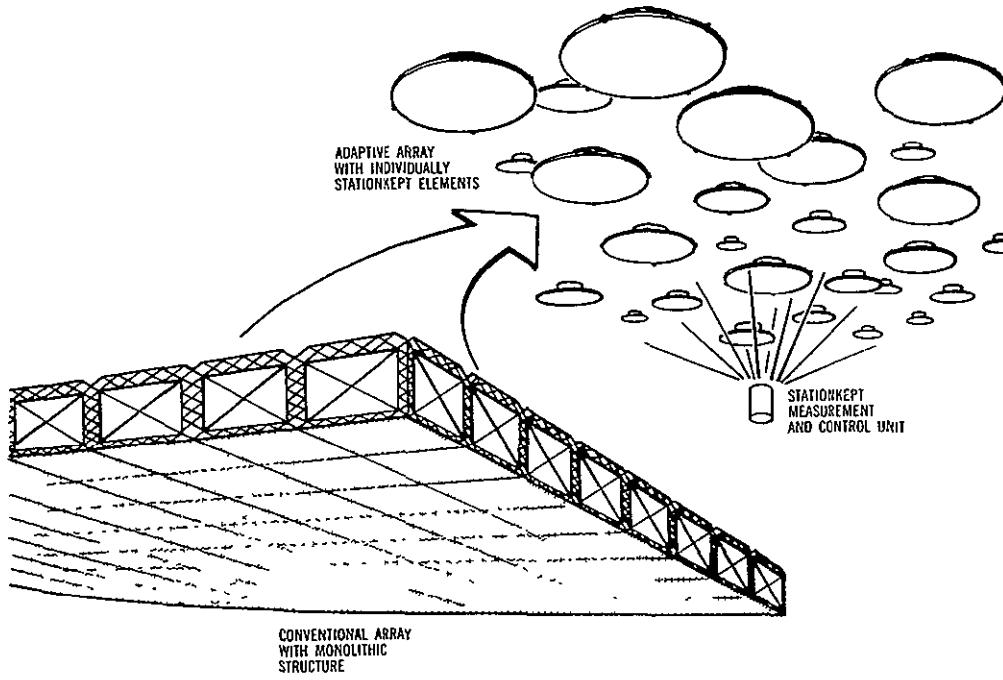


Figure 4-1. Large Antennas in Space

b. Optics

A dramatic increase in optical gathering power and resolution will also occur. Adaptive deformable optical segments should allow construction of high quality "single" apertures or dense arrays. Thin film structures should support much larger, though lower imaging quality mirrors. Application of adaptive stationkept techniques similar to those of the microwave antennas illustrated in Figure 4-1, controlling appropriate films or surfaces for phase error control, should make possible very large coherent optical arrays with the elements close or very far spaced. Thin film and composite materials will be used to attain a weight per unit projected area of as low as  $0.02 \text{ lb}/\text{ft}^2$  for the film reflectors, and  $30 \text{ lb}/\text{ft}^2$  for large high energy reflectors.

c. Information Processing

The ability to process information has made the most dramatic increases since just prior to the dawn of the space age. The next 25 years

should see a continued phenomenal growth in capability as large-scale microcircuit integration is fully utilized, with dramatic improvements in space computers becoming available. Such features as fault-tolerance, self-programming, artificial intelligence, decentralized processing, and tiny size combined with great speed and power should become routine.

This capability will allow huge quantities of data to be gathered as well as processed in space, with only minimal message rates bearing non-redundant vital messages disseminated to the surface. This ability to process data is fully utilized in many of the system concepts discussed in Section 5.

## 5. INITIATIVES (SPACE SYSTEM CONCEPTS)

The application of the advanced technology thoughts and projections described in Section 4, together with the general principles and perspectives of space applications and operations addressed in Section 3 resulted in the collection and innovation of over 100 space system concepts (initiatives).

The concepts were generated without imposing limitations due to current technology, current or projected budgets, policies, treaties, etc., so that they would be representative of what could be done given the intent. Furthermore, no calculation of cost-benefit was attempted, and all concepts which could be quantitatively defined and appeared to have some utility were included regardless of their merit or lack of merit compared to terrestrial approaches or to other space approaches. In addition, some of the concepts could materially impact the fabric of society if implemented, but that societal impact was not specifically identified or evaluated in this study.

None of the initiatives are advocated per se by the study team, The Aerospace Corporation, or NASA, though some of the general application areas illustrated probably could benefit the National Space Program.

The initiatives represent concepts of different technological difficulty and risk, varying from modest satellites which are straightforward extensions of current techniques and which could be orbited with low risk in the early 1980's to those which require great advances in technology, require major national commitments, and might even pose some hazards in their application. In order to clearly identify their risk, they have been divided into four categories as defined in Table 5-1, and the discussion will follow this categorization scheme, though in the main text (Volume II), the concepts are discussed by their areas of application (personal, civic, industrial, government, international, and scientific).

The military initiatives are only discussed in the classified version of the report.

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Table 5-1. Categorization of Initiatives - Degree of Risk

CATEGORY I - (LOW)

- READILY EXTRAPOLATED FROM CURRENT TECHNOLOGY
- RELATIVELY LOW TECHNOLOGICAL RISK.
- NO HAZARDS ASSOCIATED WITH OPERATION

CATEGORY II - (MEDIUM TECHNOLOGY)

- CONSIDERABLE EXTRAPOLATION OF CURRENT TECHNOLOGY
- DEMONSTRATION PROGRAMS REQUIRED AS PROOF-OF-CONCEPT
- PHENOMENOLOGY WELL UNDERSTOOD
- NO HAZARDS ASSOCIATED WITH OPERATION

CATEGORY III - (MEDIUM PHENOMENOLOGY)

- PHYSICS UNDERSTOOD, BUT PHENOMENOLOGY NUMBERS NEED VERIFICATION
- TECHNOLOGY CAN PROBABLY BE EXTRAPOLATED FROM CURRENT STATUS
- DEMONSTRATION PROGRAMS REQUIRED AS PROOF-OF-CONCEPT
- NO HAZARDS ASSOCIATED WITH OPERATION

CATEGORY IV - (HIGH)

- GREAT ADVANCES IN TECHNOLOGY REQUIRED
- FAR FUTURE APPLICATION - CONCEPTUAL ONLY
- CONSIDERABLE HAZARDS POSSIBLY ASSOCIATED WITH OPERATION

5.1 LOW-RISK CONCEPTS (Category I)

Twenty-six initiative concepts were conceived and collected in this category. Of these, ten concepts perform primarily communications functions, nine primarily observation functions, and six primarily support functions. Most are intended to allow average citizens to perceive personal benefits from space, and to provide incentives to industry for private investment in satellites and user equipment. Additionally, several concepts are ideally suited for international projects, and several have scientific as well as earth-oriented applications value.

Most of the communications initiatives were designed to allow communications to and from very large numbers of very small and inexpensive user terminals, thus placing the burden of high power, large antenna aperture, and extensive switching on the space segment. The satellites utilized would usually be at geostationary altitude to allow the use of one (or at most a few) satellites per function. Each satellite would utilize a multibeam antenna which would allow large area coverage with

high gain, while simultaneously conserving spectrum by reusing each channel many times. Further, the use of high (microwave) frequencies would allow the user equipment antenna to be physically small. The combination of low power and small antenna would result in small, lightweight, portable, and inherently inexpensive user terminals..

One application of such a concept is for truly personal communications, utilizing "Dick Tracy wrist radios," which is illustrated in Figure 5-1. This low risk concept could provide millions of people with high-quality fade-free, interference-free communications which could be used for pleasure, business, emergency call, "panic-button," search/rescue beacon, police command/control, national or local voting and polling terminal, health monitor, time-corrected watch, and many other functions in the 1985-1990 time period. The user terminal would utilize the same technology now available in digital watches, and volume production could make these terminals very low priced and available to all.

• PURPOSE

To allow citizens to communicate through exchanges by voice, from anywhere.

• RATIONALE

Mobile telephones are desirable, but should be wrist worn. Uses include emergency, recreation, business, rescue, etc.

• CONCEPT DESCRIPTION

Multichannel switching satellite and wrist transmitter-receivers connect people anywhere to each other directly or to telephone networks. Analog or vocoded voice used.

• CHARACTERISTICS

• WEIGHT	16,000 lb
• SIZE	200 ft dia antenna
• RAW POWER	21 KW
• ORBIT	Synch. Equat.
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1990
• IOC COST (SPACE ONLY)	300M

• PERFORMANCE

25,000 simultaneous voice channels, each shared by up to 100 users: 2.5 million people communicate by normal voice.

• BUILDING BLOCK REQUIREMENTS

• TRANSPORTATION	Shuttle and large/tandem tug or SEPS
• ON-ORBIT OPERATIONS	Automated or manual servicing unit; assembly on orbit
• SUBSYSTEMS	Altitude control; antenna; processor; repeater
• TECHNOLOGY	Large multibeam antenna; multi-channel repeater, LSI processor, multiple-access techniques
• OTHER	Wrist transceiver, LSI technology

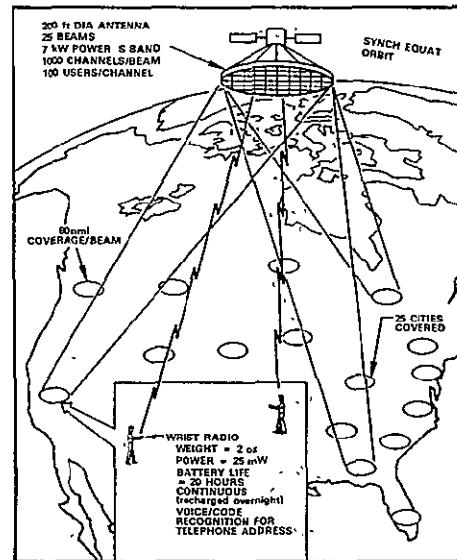


Figure 5-1.. Personal Communications Wrist Radio

The satellite would function as a multichannel telephone switching center, routing and billing the users automatically. The technology required is current state of the art, due to be operated in space in 1981 on a smaller scale. The satellite could be orbited by a shuttle and large or tandem orbital transfer vehicle or assembled in orbit using multiple flights of current upper stages. Servicing in orbit would be desirable to extend operational life and reduce initial costs of this electronically complex satellite.

An application of similar, though smaller satellites addresses an extremely vital problem -- that of aiding in the prevention of diversion or hijacking of nuclear materials used as fuels for nuclear power reactors (as well as other toxic or hazardous materials). In this application, the "tagging" of nuclear reactor fuel materials, assemblies, or shipment casks with small radio transmitters, and the subsequent tracking of their signals from space, would enable the hijacking or diversion of nuclear materials to be instantly detected, minimizing the danger of nuclear terrorism or blackmail. The concept is illustrated in Figure 5-2.

- **PURPOSE**  
To detect and locate all nuclear reactor fuel elements continuously wherever they are.
- **RATIONALE**  
Real-time monitoring of location of nuclear material needed to prevent proliferation of weapons and nuclear blackmail.
- **CONCEPT DESCRIPTION**  
Each assembly or container is tagged with a microwave generator in a tamper-indicating case. The uniquely coded signals are transponded by four satellites and the position computed by time-difference-of-arrival on the ground.
- **CHARACTERISTICS**

• WEIGHT	3000 lb
• SIZE	42 ft antenna
• RAW POWER	300 W
• ORBIT	Synch. Ellipt. / Incl.
• CONSTELLATION SIZE	4
• RISK CATEGORY	I (Low)
• TIME FRAME	1985
• IOC COST (SPACE ONLY)	270 M
- **PERFORMANCE**  
Each fuel assembly identified and located to  $\pm 500$  ft continuously, whether in a reactor building, in transit, or in storage; 10,000 assemblies tracked simultaneously.
- **BUILDING BLOCK REQUIREMENTS**
  - TRANSPORTATION
  - ON-ORBIT OPERATIONS
  - SUBSYSTEMS
  - TECHNOLOGY
  - OTHER

Shuttle and Tug  
Automated or manual service unit  
Antenna, transponder  
Multibeam antenna - multi-channel transponder  
LSI ground multi-channel cross-correlator receivers; high temperature and high radiation resistant vacuum tube transmitter and code generator; thermopile electrical generator; tamper alarm. Roof transponders.

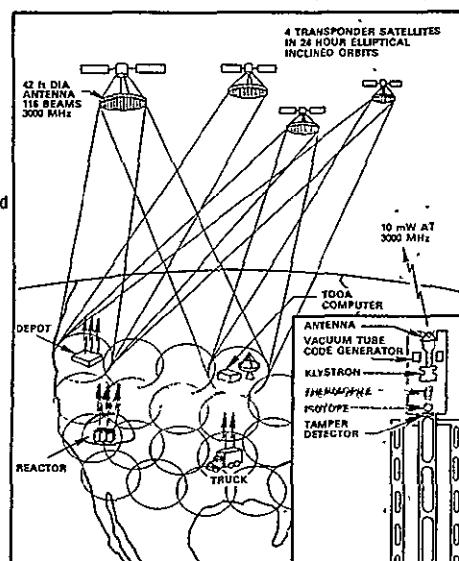


Figure 5-2. Nuclear Fuel Locator

The "tagging" transmitters would be located and tracked by time-difference of arrival of their signals as transponded through three or four satellites. The signals could readily pass through the walls of buildings, trucks, factories, etc., either by proper construction or by the provision of suitable transponders. The signals would be "on" at all times from the manufacture of the material, through shipment and use, until their arrival at the destination or reprocessed. Twenty satellites would be needed to cover the entire world for preventing international blackmail. The satellites would be near-term, low-risk devices needing but a shuttle and IUS or tug for transportation, and automated or manual servicing for their upkeep.

The last example of near-term, low-risk concepts employs recent advances in mode-locked lasers, which make possible the generation and detection of pulses of picosecond duration ( $10^{-12}$  sec). This implies an ability to perform ranging to an accuracy of 0.3 millimeters ( $\approx 10/1000$  in.) essentially independent of range. By emplacing corner reflectors on both sides of earthquake fault lines, relative movements of such magnitudes could be detected from a satellite equipped with such a laser, and utilized for earthquake prediction. Similarly, relative range could be obtained to fixed and floating reflectors on bodies of water, resulting in extremely sensitive remote water height measurements for flood, drought, or water resource predictions. The concept is illustrated in Figure 5-3.

The real advantage of making such measurements from space rather than from ground or aircraft, is the enormous number of measuring points which can be accessed in very short periods of time by the same calibrated instrument, thus obtaining large-area patterns nearly simultaneously yet combined with finely detailed individual observations. This is a low-risk, lightweight laser application system which probably could be orbited in the mid 80's using no more than a shuttle and IUS or Tug. Orbital servicing could be performed at synchronous or low altitude for essentially unlimited life.

- **PURPOSE**  
To make precision measurements in many places in rapid succession for aid in earthquake prediction, water resources establishment, disaster use, etc.
- **RATIONALE**  
Prediction of earthquakes, floods, droughts, and accurate water resources would be of great social and economic benefit.
- **CONCEPT DESCRIPTION**  
Picosecond ( $10^{-12}$  sec) pulsed laser radar in orbit obtains precision differential range measurements from corner reflectors implanted on both sides of faults, river banks and floats, etc.
- **CHARACTERISTICS**

• WEIGHT	800 lb
• SIZE	0.5 m optics
• RAW POWER	250 W
• ORBIT	Geostationary
• CONSTELLATION SIZE	1
• RISK CATEGORY	I (Low)
• TIME FRAME	1985
• IOC COST (SPACE ONLY)	\$50 M
- **PERFORMANCE**  
Relative range obtained to  $\pm 0.3$  millimeters at any number of points separated by 100 meters or more.  $10^3$  instrumented points can be measured every hour.
- **BUILDING BLOCK REQUIREMENTS**

• TRANSPORTATION	Shuttle, IUS/Tug
• ON-ORBIT OPERATIONS	Automated or manned servicing
• SUBSYSTEMS	Picosecond receiver, transmitter, 2 $\mu$ r pointing
• TECHNOLOGY	Streak camera converter, mode locked laser and switch.
• OTHER	

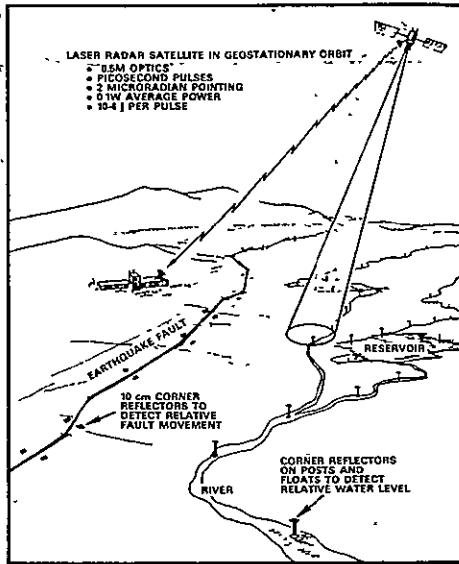


Figure 5-3. Earthquake Fault Movement and Water Level Indicator

Other observation concepts include higher resolution optical and radar earth resources/pollution satellites, fire detection, and ocean resource location satellites utilizing infrared sensors. Additional low-risk applications of large multibeam antenna communications satellites in conjunction with small, low power user terminals include electronic mail distribution, disaster communications, air traffic control, T.V. broadcast to home receivers, "hot-line" links between all heads of state, three-dimensional image (holographic) teleconferencing, and interplanetary T.V.-bandwidth links. Support concepts include the reading out of very large numbers (billions) of surface sensors or switches, each with a tiny microwave transmitter for use in energy flow monitoring and control, burglar alarms for private or public buildings, and other applications.

## 5.2

MEDIUM TECHNOLOGICAL RISK CONCEPTS (Category II)

Six initiative concepts were identified in this category, which requires considerable development and orbital demonstration of the technology.

One example would use linear satellite antennas measuring in the order of two-miles long to provide a personal navigation function to an unlimited number of users with "wrist radio" receivers, by setting up extremely narrow sweeping radio beams from space. These beams would cause pulses in the simple wrist receivers whenever the beam swept over the wearer. Counting the timing of such pulses using a simple oscillator "clock," the wrist radio sets would indicate the wearer's location, heading, and even speed on a small digital light display not unlike that of today's digital watches. Such a concept, illustrated in Figure 5-4, could provide an unlimited number of people with an all-weather capability of navigation.

- PURPOSE

To provide accurate relative position location with very inexpensive user equipment.

- RATIONALE

Navigation system costs are dominated by user equipment costs.

- CONCEPT DESCRIPTION

Narrow beams are swept over the U.S. by large phased arrays in space. Very simple receivers measure time elapsed between pulses received and display distances (N-S, E-W) to fixed point

- CHARACTERISTICS

- WEIGHT

3000 lb

- SIZE

2 nmi cross

- RAW POWER

2 kW

- ORBIT

Sync Equat

- CONSTELLATION SIZE

1

- RISK CATEGORY

II (Medium)

- TIME FRAME

1990

- IOC COST (SPACE ONLY)

100 M

- PERFORMANCE

- User position located to 300 ft every 10 sec relative to a fixed location < 100 nmi away.
- User receiver can cost less than \$10 in mass production.

- BUILDING BLOCK REQUIREMENTS

- TRANSPORTATION

Shuttle and Tug

- ON-ORBIT OPERATIONS

Manned or automated assembly and servicing units

- SUBSYSTEMS

Antenna with independently stationkept subunits.

- TECHNOLOGY

Ion thruster, adaptive RF phase control, laser master measuring unit

- OTHER

LSI receivers

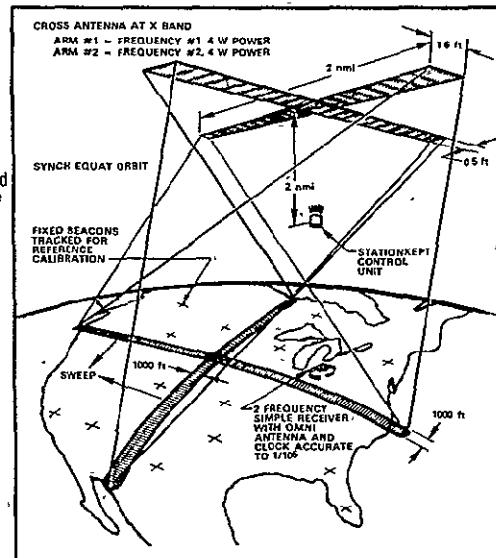


Figure 5-4. Personal Navigation Wrist Set

The large antenna in space would be used for its ability to generate extremely narrow beams, rather than for its aperture. The antenna would be constructed of a large number of stationkept subsatellites, position and phase-controlled by stationkept measurement and control satellites to act as a coherent linear electronically scanned crossed array. Alternatively, the antenna arms could be supported by a monolithic structure holding the required flatness across the array. This satellite concept is placed into Risk Category II due to the unproven status of the stationkept antenna array (or the difficulty in maintaining surface flatness of about 1/4 in. across a two-mile long structure).

Combining communications and navigation functions into a single "wrist radio" type of personal terminal would allow its use for voice communications, rescue beacon, emergency transmitter, "panic button," voting and polling terminal, navigation set, compass, speedometer, medical monitor, civil defense alarm, and many other functions. This type of service, whether developed by government, the private sector, or both in concert, could really allow large numbers of ordinary people to directly and personally benefit from space in the course of their everyday lives. Savings might ensue in the operations compared to use of today's techniques, and new functions provided not feasible otherwise. Furthermore, the operation of the satellite and user terminals could be a service provided by private industry, with returns on the initial investments possible through use fees. Billing for use could be automatically performed in a way not unlike today's telephone system operation.

The satellite would have to be assembled in space in final orbit, and initialized into service and maintained using either manned or unmanned vehicles. The low density of satellites of this type would place demands on packaging for minimum volume during boost, but a shuttle and IUS/Tug would probably suffice for transportation.

A second concept discussed in this risk category would combine navigation and communications functions to aid in locating "lost" vehicles or packages, or to aid in the prevention of their theft or hijacking. The

railroad industry might benefit from being able to instantly and continuously locate and identify all railroad cars. Thefts, losses, unaccounted disappearances, and many delays due to errors in routing of packages, crates, and other items shipped by car, rail, truck, or ship could also be minimized by location determination on a continuous or on-demand basis. These and other applications could be satisfied by "tagging" each vehicle or item shipped with a small radio set which would locate itself and communicate its location to dispatch centers on a periodic or continuous basis. One approach to such a package or vehicle locator would capitalize on the ability of each vehicle or package to determine its own position with a tiny, inexpensive receiver utilizing the "personal navigation" type of satellite illustrated in Figure 5-4, and report it to the dispatch control center upon query or periodically.

An extremely large number of vehicles or packages could be tracked using such a system, since a simple code query and reply need not take more than a small fraction of a second, permitting up to one billion per hour (in the illustrative example) to be located to an accuracy better than 300 ft in all kinds of weather and 24 hours a day. Applications such as this are categorized as medium risk since they use the two-mile long antenna navigation satellite. They would be considered low risk if they were to depend on nearer-term technology for location determination, such as Loran receivers, etc. This example, as the previous ones would allow services to many tiny and inexpensive user sets by virtue of transferring much of the complexity and size to the space segment, in keeping with the general perspectives discussed in Section 3.

Additional medium-risk satellite uses include the detection and location of border intrusions by illegal aliens or drug traffickers, bistatic radar illumination of the seacoasts for inexpensive small boat user radar, nuclear waste disposal into escape orbits, and sunlight reflection to provide nighttime illumination.

### 5.3 HIGH-RISK CONCEPTS (Category IV)

Eight initiative concepts have been identified in this category. They are far-future applications which require great advances in technology, imply some operating risk, or both. The concepts generally deal with the generation, delivery, and distribution of large amounts of energy to cities or to aircraft in flight. One concept was conceived at The Aerospace Corporation for greatly increasing the efficiency of solar power subsystems, and it is included in this category applied to energy delivery from space. Several energy distribution concepts were identified in which space would act as an energy common-carrier for multinational energy pooling. The satellites would be very massive, weighing millions of pounds, and generally require development of larger-lift-vehicles than the space shuttle, large orbital transfer vehicles, and extensive orbital assembly and servicing operations.

### 5.4 APPLICATIONS SUMMARY

A summary listing all of the civilian initiatives is shown in Figure 5-5, categorized by area of application as well as risk. Many of the functions are readily deduced from the titles of the concepts. Each is described in detail in Volume II. Each requires further analysis and definition in dedicated system studies, however the support requirements of the initiatives taken as a group are felt to well represent the real needs of this or almost any other grouping of initiatives which could be prepared today.

Several of the initiative concepts have similar satellite subsystem and system requirements, though performing different functions. Multi-function satellites are clearly suggested, but have not been specifically identified as initiatives. In the far term, multi-functional national orbital facilities are expected to appear and are discussed in Volume II, Section 2.

<u>RISK CATEGORY</u>		<u>RISK CATEGORY</u>	
<u>PERSONAL APPLICATIONS</u>		<u>GOVERNMENT APPLICATIONS</u>	
- Personal Communications Wrist Radio	I		
- Emergency/Rescue Wrist Beacon	II		
- Personal Navigation Wrist Set	II		
- Voting/Polling Wrist Set	I		
<u>CIVIC APPLICATIONS</u>		<u>COMMUNICATIONS</u>	
- Disaster Communications Wrist Radio	I	- Voting/Polling Wrist Set	I
- All-Aircraft Traffic Control	II	- Electronic Mail Transmission	II
- Urban/Police Wrist Radio	II	- Border Surveillance	II
- Car Speed-Limit Control	I	- Nuclear Materials Locator	I
		- Library Data Sharing	I
<u>INDUSTRIAL APPLICATIONS</u>		<u>OBSERVATION</u>	
- Burglar Alarm/Intrusion Detection	I	- High Resolution Resources/Pollution Observatory	II
- Vehicle / Package Locator	II	- Water Level and Fault Movement Indicator	I
- 3D Holographic Teleconferencing	II	- Atmospheric Temperature Profile Sounder	III
- Advanced T.V. Broadcast	I	- Forest Fire Detection	I
- Advanced Resources/Pollution Observation	I	- Ocean Resources Location	I
<u>INTERNATIONAL APPLICATIONS</u>		<u>SUPPORT</u>	
- Nation-Nation "Hot Lines"	I	- Passive Coastal Anti-Collision Radar	II
- Multinational Air Traffic Control Radar	I	- Night Illuminator	II
- Small Terminal Intelsat Network	I	- Energy Delivery and Distribution (5 concepts)	IV
- Earth Resources Data Sharing	I	- Energy Consumption Monitor	I
- Energy Distribution Relay	IV	- Aircraft Laser Beam Powering	IV
- U.N. Truce Observation Satellite	I	- Nuclear Waste Disposal	II
		<u>SCIENTIFIC APPLICATIONS</u>	
		- Astronomical Super-Telescope	IV
		- Interplanetary T.V. Link	II
		- Atmospheric Temperature Profile Sounder	III
		- Ocean Resources and Dynamics Sensor	I
		- Water Level and Fault Movement Indicator	I

Figure 5-5. Applications Summary and Risk Estimation

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## 6. NATIONAL GOALS AND SPACE FUNCTIONS IN THE FUTURE ENVIRONMENT

Brief consideration was given to the international and domestic environments which were likely to exist in the 1980-2000 time period. The sources were primarily discussions with knowledgeable people, previous thought in this area, review of literature dealing with general forecasting, and specific reports and books addressing the subject. However, these views must be considered those of the authors, not necessarily endorsed by NASA or other Aerospace Corporation personnel.

The purpose of this consideration was to enable the interpretation of the environment in terms of the National goals, so that the specific goals or requirements for space systems could be derived and related to the roles they could play in support of the National goals. While the environments considered are only discussed in the main text, the possible contribution of space functions to National goals is found in Tables 6-1, 6-2, and 6-3. These tables indicate that space could contribute to goals affecting many facets of people's lives, as well as industry, government at all levels, international relations, and intellectual pursuits.

Table 6-1. Potential Space Contributions to  
Public Service and Humanistic Goals

GOALS	SPACE FUNCTIONS
1. Promotion of International Peace	<ul style="list-style-type: none"><li>• Treaty Verification</li><li>• Nation-Nation "Hot Lines"</li></ul>
2. Aid to General Safety	<ul style="list-style-type: none"><li>• Disaster Warning and Control</li><li>• Drought Prediction</li><li>• Transportation Safety Control</li></ul>
3. Protection of the General Environment	<ul style="list-style-type: none"><li>• Pollution Monitoring</li><li>• Preservation of the Ozone Layer</li><li>• Prediction of Ionospheric Disturbances</li><li>• Preservation of Near-Space Environment</li></ul>
4. Individual Aid and Protection	<ul style="list-style-type: none"><li>• Personal Communications, Emergency, and Routine</li></ul>
5. Aids to Crime Control	<ul style="list-style-type: none"><li>• Night Illumination and Searchlights</li><li>• Police Communications and Control</li><li>• Traffic Control</li></ul>
6. Internal Security	<ul style="list-style-type: none"><li>• Border Surveillance Against Illegal Entry</li><li>• Control of Nuclear Materials</li></ul>
7. Improved Relation of Citizens to Government	<ul style="list-style-type: none"><li>• Better Communications Access Between People and Government</li></ul>
8. Enhancement of Satisfaction	<ul style="list-style-type: none"><li>• Develop Pride in Significant Accomplishments</li></ul>

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Table 6-2. Potential Space Contributions to Materialistic Goals

GOALS	SPACE FUNCTIONS
1. International Cooperation	<ul style="list-style-type: none"> <li>● International Space Projects</li> <li>● Share Benefits of U. S. Space Projects</li> </ul>
2. Aid in U. S. Position of World Leadership	<ul style="list-style-type: none"> <li>● Demonstration of Innovative Problem-Solving; Mastering of High Technology; International Enterprises, etc.</li> </ul>
3. Aid in Increasing Industrial Activity	<ul style="list-style-type: none"> <li>● Resource Exploration</li> <li>● Pollution Monitoring</li> <li>● Weather Prediction and Control</li> <li>● Transportation Control</li> <li>● Communication Facilities</li> <li>● Energy Management and Generation</li> </ul>
4. Aid in Agricultural and Forest Management	<ul style="list-style-type: none"> <li>● Weather Prediction and Control</li> <li>● Crop Prediction</li> <li>● Forest Surveys</li> </ul>
5. Provision of New Resources	<ul style="list-style-type: none"> <li>● Energy Delivery</li> </ul>
6. Acquisition of New Environment	<ul style="list-style-type: none"> <li>● Large, High Vacuum</li> <li>● Zero g</li> </ul>
7. Use of Space to Remove Hazards From Earth	<ul style="list-style-type: none"> <li>● Perform Hazardous Processes</li> <li>● Disposal of Wastes</li> </ul>

Table 6-3. Potential Contributions to Intellectual Goals

GOALS	SPACE FUNCTIONS
1. Aid in Determination of Origin of Solar System	<ul style="list-style-type: none"> <li>● Planetary exploration and geology</li> <li>● Nature of asteroids</li> <li>● Cometary research</li> </ul>
2. Aid in Understanding Galactic Structure and Dynamics	<ul style="list-style-type: none"> <li>● Infrared astronomy 5-500 <math>\mu</math>m</li> <li>● Ultraviolet astronomy</li> </ul>
3. Aid in Understanding Cosmology	<ul style="list-style-type: none"> <li>● X-ray astronomy</li> <li>● Observation of distant objects</li> <li>● Intergalactic materials study</li> </ul>
4. Verification of Physical Laws in the Large	<ul style="list-style-type: none"> <li>● General relativity experiments</li> <li>● Invariance of velocity of light experiments</li> <li>● Experiments on homogeneity and isotropy of empty space in the large</li> </ul>
5. Verification of Basic Physical Laws in the small	<ul style="list-style-type: none"> <li>● Precise measurement of gravitational constant</li> <li>● Precise measurement of equivalence of inertial and gravitational mass</li> </ul>

## 7. SUPPORT REQUIREMENTS

This section of the report derives and presents the requirements for space transportation, assembly and servicing stages, and orbital support facilities (lumped into the term "building blocks") and technology.

The outputs of the previous portions of the study were utilized in generation of six alternate future world descriptions. For each future world a set of executive directives was derived, intended for guidance to the NASA and DoD for structuring their programs consistent with the kind of scenario and the latent information in its definition. These executive directives were then amplified for each scenario, resulting in specific instructions for the construction of program plans responsive to the scenarios, and formatted using the functional system categorization scheme evolved in the first half of the study. Thus for each space function, instructions were developed to enable six alternate program plans to be generated.

The program plans were thus developed utilizing the specific instructions derived above to select initiatives from the functional system options data bank, which contains the initiatives collected and conceived during the first half, as well as initiatives based on the NASA and DoD mission models. These program plans were developed as a function of time, and their yearly cost was estimated. The sum of the costs of the program plans was then compared with the budget contained in the executive directives for the particular world being considered. If the costs of the program plan were grossly different than the budget requirements in the particular world, the program plan generation method was iterated until a rough correspondence was obtained.

Once the six alternate program plans were thus generated, supporting "building block" transportation vehicles, orbital support facilities, and needed technologies were extracted for each program plan. It was this information which was utilized for assembling the output of the study, i.e., the separate and common NASA/DoD needs for building blocks and technology for each particular world considered, as well as general development plans for systems, building blocks, and technologies which protect most of the options and are not dependent on particular assumptions of the future.

## 7.1 ALTERNATE WORLD FUTURES

The six scenarios which were developed in this study represent combinations of three extremes of international tension and four domestic environments. The first two scenarios represent a balance in international relations between the major powers, combined in the first scenario with an isolationist domestic environment and in the second scenario with an expansionistic domestic environment. The third and fourth scenarios represent an unstable, maneuvering international balance, combined in the third scenario with a conservative domestic environment and in the fourth scenario with an innovative expansionistic domestic environment. The fifth and sixth scenarios represent a sure confrontation with an axis of hostile powers, leading to inevitable general nuclear war in the year 2000 in the fifth scenario, and in the year 1990 in the sixth scenario. The respective domestic environments are attitudes of ambiguity in the fifth scenario and no-nonsense preparedness for the coming holocaust in the sixth. These scenarios are discussed in more depth in Volume IV, and illustrated in Figure 7-1.

The scenarios described above probably span the spectrum of international and domestic situations which will define the U.S. environment in the period 1980-2000. No position was taken as to which world we are currently in, which world is most likely, or whether any world described is likely or realistic. However, it is reasonable to state that this spectrum is probably broad enough to include many of the dominant features of likely developments in international and domestic situations for the next 20-25 years; but the exact shape of those developments is not known, probably not predictable, and not needed for this study.

## 7.2 PROGRAM PLANS

Forty-two program plan data sheets were prepared using the initiative concepts, functional categorization scheme, and functional system options developed in the main text together with the planning directives derived from the future scenarios described in Section 6.1. The plans contain time-phased sequences of capability in each functional area, and estimated costs of each function.

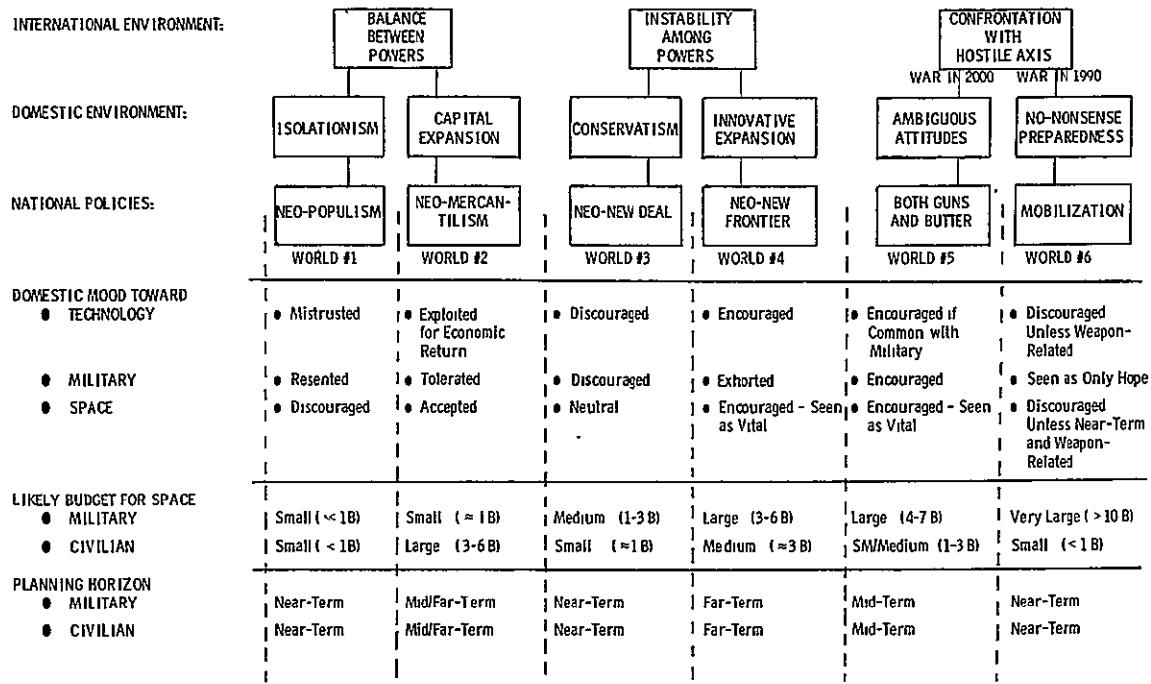


Figure 7-1. Spectrum of Representative Scenarios

### 7.3 GENERAL SUPPORTING NEEDS

The supporting needs of each of the program plans illustrated above were extracted and divided into building blocks and technologies. A general picture of the maximum number of mission opportunities for each class of supporting building block is shown in the graph of Figure 7-2. Note that these represent mission opportunities, not a traffic model, and that the missions include all initiatives in this report as well as most of the systems appearing in the 1973 NASA STS Mission Model and the 1974 DoD STS Mission Model. Furthermore, there exists a degree of redundancy, since some functionally similar missions could be performed by the same space system, yet were treated as separate missions in the additions leading to this graph.

The maximum number of mission opportunities yields several key messages:

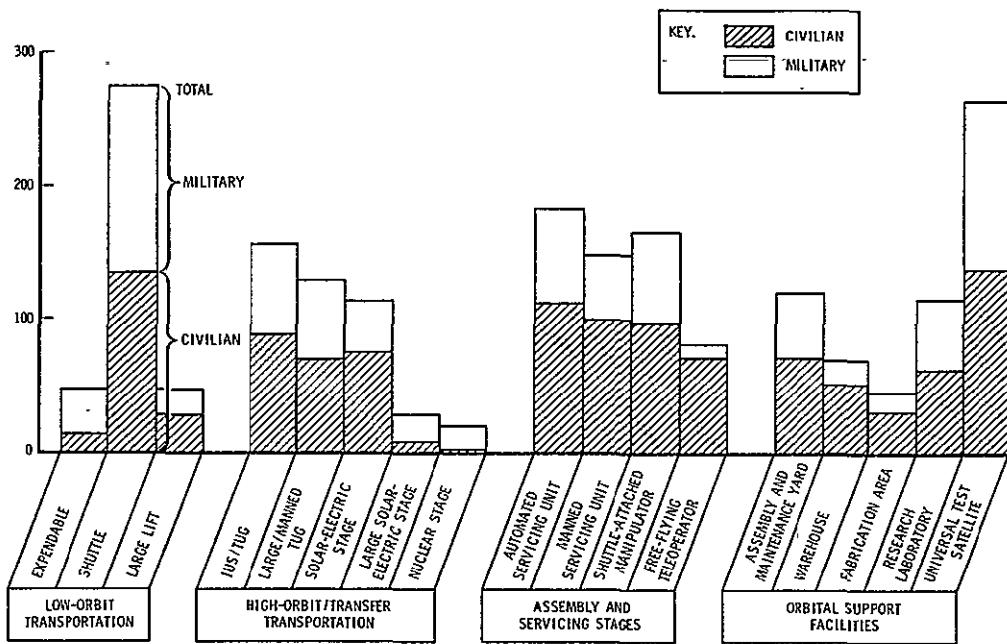


Figure 7-2. Number of Mission Opportunities for Transportation and Support

1. The shuttle is a highly useful and versatile booster.
2. Though there are foreseen several needs for expendable boosters and vehicles of larger lift than the shuttle, those needs are only about 10 percent of the needs for the shuttle (though since the priority of all missions is considered of equal weight in this graph, the conclusion cannot be reached from this data alone that there is little need for boosters other than the shuttle).
3. The need for orbital transfer transportation vehicles is about half of that into low orbit, i.e., about half of the systems require an upper stage boost.
4. The IUS and Tug can satisfy about half of the upper stage needs.
5. There is a strong call for a Solar Electric Stage, particularly for civilian missions, and an equally strong call for a large/manned tug. An upper stage much larger than the 25 kW Solar Electric Stage is required in only a few systems (see caveat in Point #2).

6. Assembly and servicing stages of some kind are needed for about half of the missions. The choice of manned versus unmanned, and attached versus freeflying teleoperator cannot be made on a gross basis, but requires detail examination of the roles of each mission
7. Orbital support facilities such as assembly and maintenance "yard" and research laboratories are needed in about half of the missions, with flexible test satellites being useful in most.

Further, the data of this section indicates that the role for man in space will probably shift from the early exploratory functions to that of builder, operator and repairman, as well as that of researcher. Since about half of the missions require some form of assembly, initialization, servicing and reconfiguration in space, man is seen emerging as an element in providing the support functions for "care and feeding" of mission-oriented satellites, and in providing and operating the orbital bases and facilities for such operations.

#### 7.4 SPECIFIC SUPPORT NEEDS

The needs for the supporting building blocks under the different conditions which will exist for each of the six alternate world futures were also collected and are contained in the main text. An illustration of their content is shown in Figure 7-3, pertaining to transportation into low earth orbit.

The sum of all the civilian and military missions (initiatives) in which there are opportunities for utilization of each class of booster are shown as a function of the world number for the alternate scenarios. These were developed by summing the support needs of each initiative called for in each program plan. The format for presentation was chosen as straight lines connecting the data points for each of the world numbers, even though it is recognized that the data only exists for each discrete world number, since the connecting lines are useful for pictorial representation and for trend extrapolation.

A cursory analysis of the data on Figure 7-3 indicates that the shuttle is a versatile, high demand booster and will continue to be so through the end of the century, compared to an expendable or a larger launch vehicle, and continues to be very much in demand regardless of the nature of the future

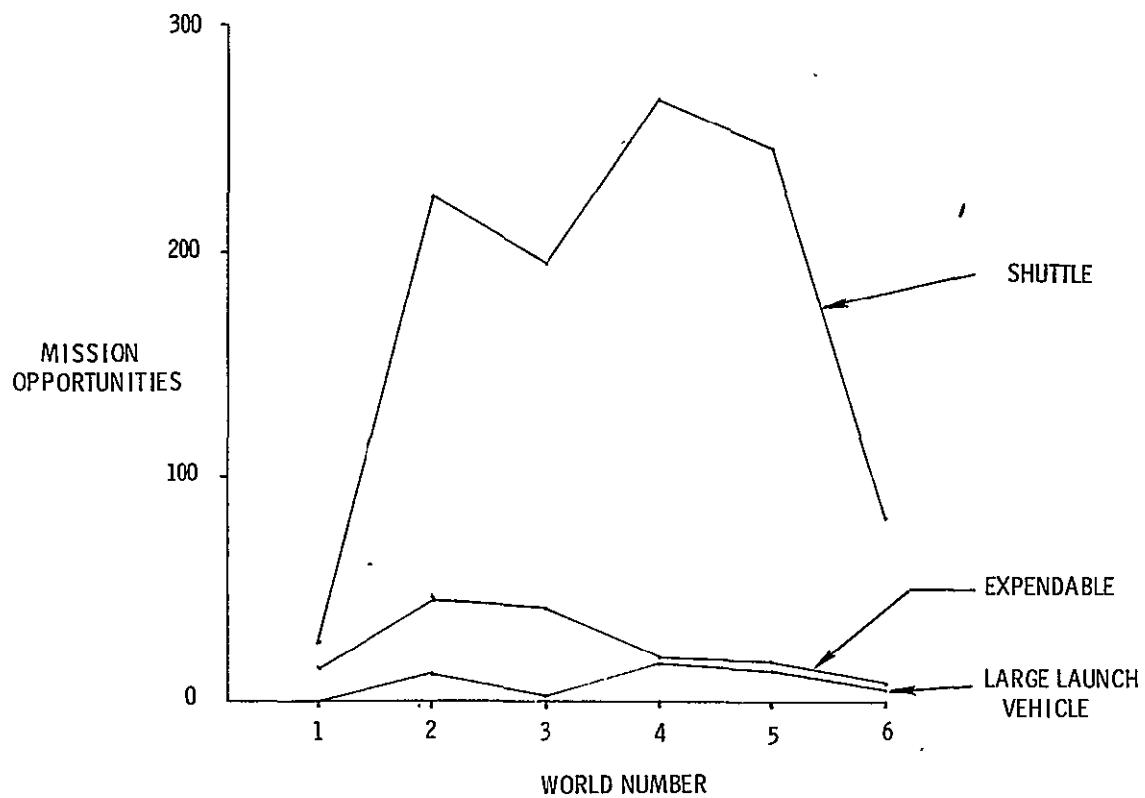


Figure 7-3. Mission Opportunities for  
Low Earth Orbit Transportation

world facing us within the choices of the alternate world scenarios. The opportunities for utilization of the shuttle are many and relatively constant for Worlds #2 through #5 inclusive, being far smaller for World #1 and for World #6, which is to be expected since Worlds #2 through #5 are more moderate views of the future calling for greater numbers of space systems. World #1 is a very austere world for the military and civilians, results in a small number of payloads, and therefore opportunities, for any booster. In World #6 the civilian opportunities drop off dramatically, most of the opportunities shown being for military operations facing up to the war in 1990. The ground rule for requirements for a larger lift vehicle than the shuttle was established rather arbitrarily in the early part of the study in the following way: if a particular space program or initiative required more than about 100 shuttle flights to establish the system, a larger lift vehicle was indicated; otherwise the shuttle was deemed an adequate booster.

Data such as presented in Figure 7-3 cannot be used by itself to make a case for not developing a large lift vehicle or for phasing out expendable boosters, because the nature of the programs requiring such boosters and their relative priorities must also be addressed. It is clear from this chart, however, that the shuttle is an extremely versatile, high demand, well thought out program of great utility, even though many of the payloads which are assumed flown in the future worlds were not conceived at the time the shuttle design was definitized.

Similar treatment of the rest of the building blocks is found in the main text. They yield results roughly comparable to that above, with mission opportunities peaking for the more "moderate" future worlds.

## 8. COMMON NASA/DOD SUPPORT NEEDS

The extraction of needs for supporting building blocks and technology which are shared by the civilian and military space communities follows readily from the data used to prepare the general and specific support requirements presented in Section 7. The following graphs present this data, expressed as a percentage of the maximum possible mission opportunities.

It is seen from Figure 8-1 that the commonality of the shuttle is high for Worlds #3, #4, and #5 and fairly high for Worlds #2 through #5, which are all the "reasonable" worlds. This is also the case for the expendable boosters. It is seen that the large lift vehicle has few common opportunities, as well as only a few percent common needs (and then only in World #4) with common needs being non-existent for any other world. This is because the large lift vehicle is only required for large far-term systems which are required primarily in World #2 by the civilian and in World #4 by the military, but only simultaneously in World #4. We can conclude that the shuttle, as well as any expendable boosters which may be needed, possess a high degree of commonality whereas the large lift vehicle does not. This conclusion must be tempered with the statement that the launch vehicle requirements for the orbital support facilities themselves were not examined, and could well change the above conclusions. Furthermore, it must be remembered that even though the absolute and common opportunities for a given device might be small, those missions could be judged extremely important, increasing the hazard of writing off any vehicle with small showing in these results.

In Figure 8-2 the commonality curves are shown for high orbit and transfer transportation. It is seen that for all the reasonable worlds the IUS and Tug have a large degree of commonality, followed very closely by the 25 kW Solar Electric Propulsion Stage, and by a large or manned version of the tug. This is particularly true for Worlds #3, #4, and #5. Some common needs also exist in World #6, but none in World #1. Again this result follows inherently from the definitions of the scenarios of those worlds. It is to be noticed that there are no common needs for the nuclear stage since most needs

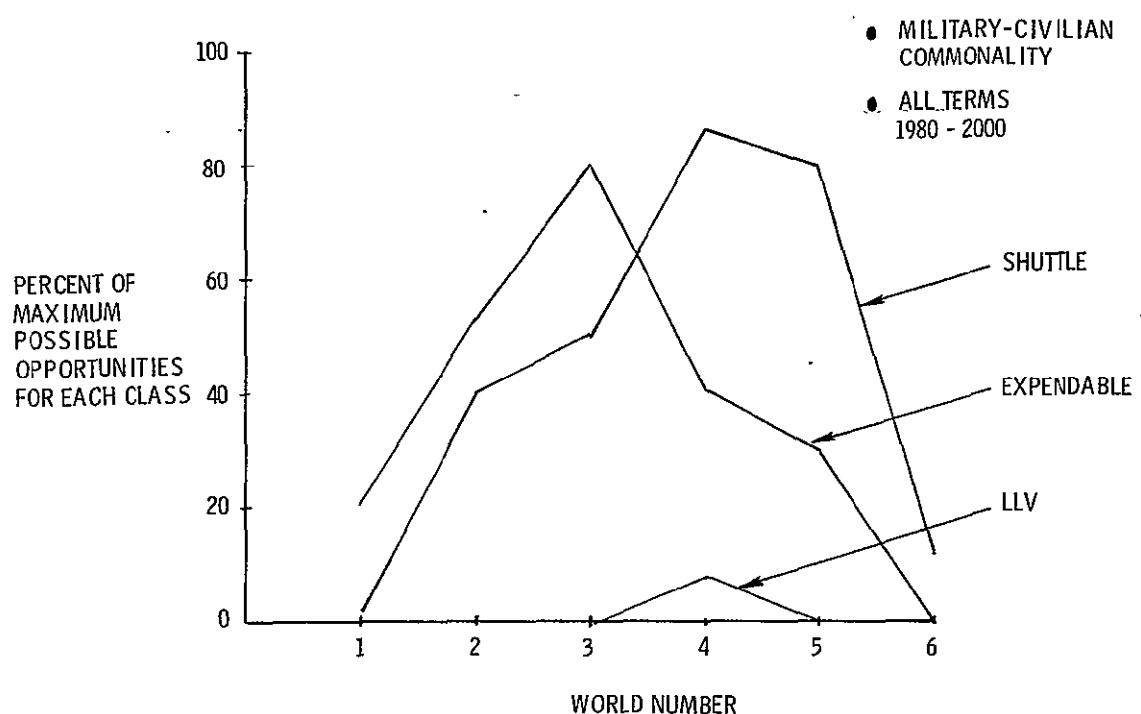


Figure 8-1. Common Needs for Low Earth Orbit Transportation

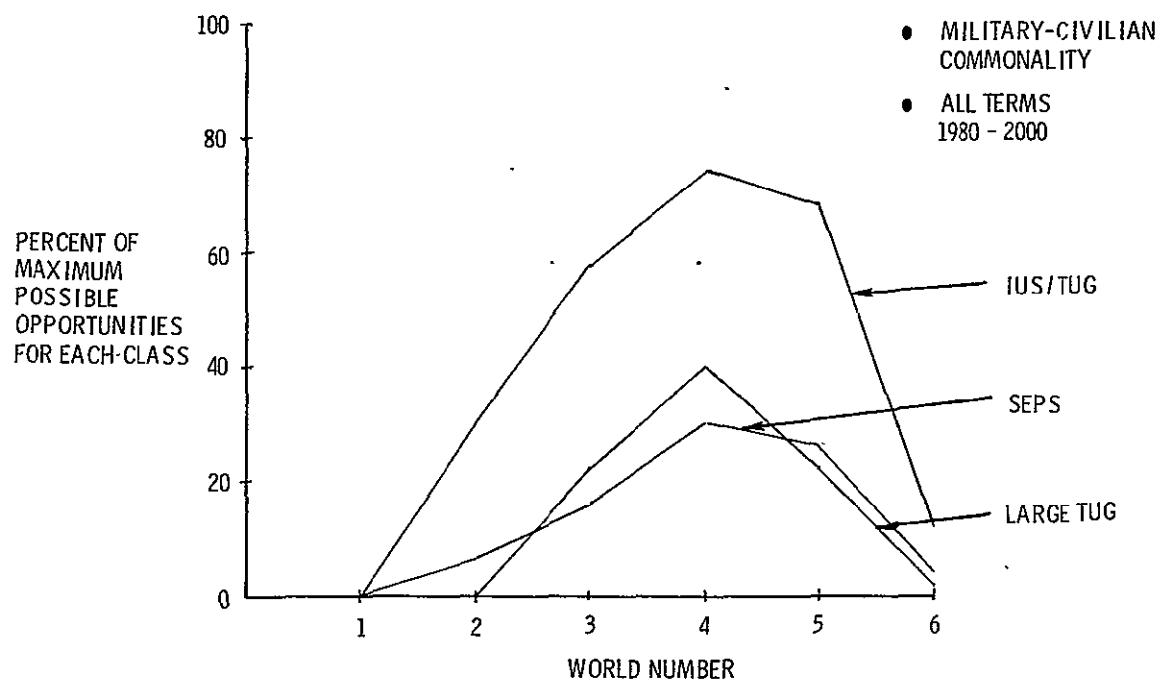


Figure 8-2. Common Needs for High Orbit/Transfer Transportation

for such a stage appear to stem from military requirements for prolonged or continuous maneuvering on orbit. (Civilian exploration of the Solar System and beyond was only very lightly treated in this study, and the latter conclusion could well be reversed upon its incorporation.)

A general feeling for common support needs emerges with reference to Figure 8-3 in which are plotted the percent of common needs for each building block in the best of the "reasonable" worlds (#2 through #5), and for the best of the "extreme" worlds (#1 and #6). It is seen that most building blocks possess a very high degree of commonality in most of the reasonable worlds, but fairly little in all the worlds, though many categories are definitely non-zero. Depending on the importance of the specific missions requiring support for all worlds, a good case may or may not be constructed for development of more supporting elements. Certainly a powerful case can be constructed for all the "reasonable" worlds.

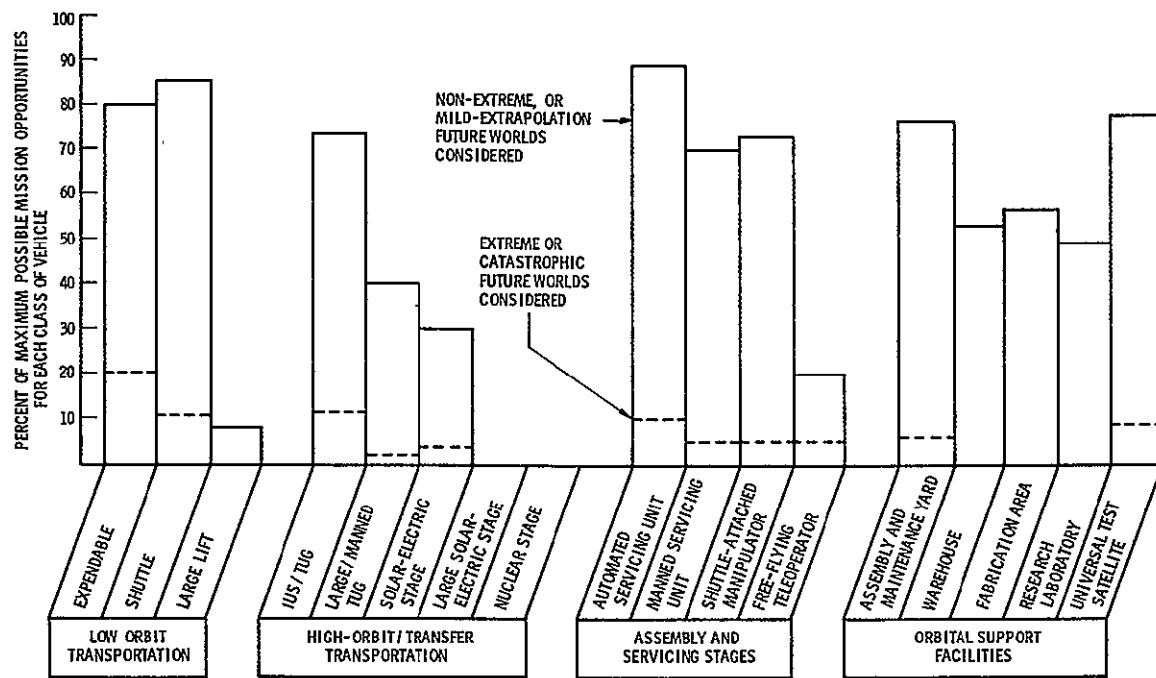
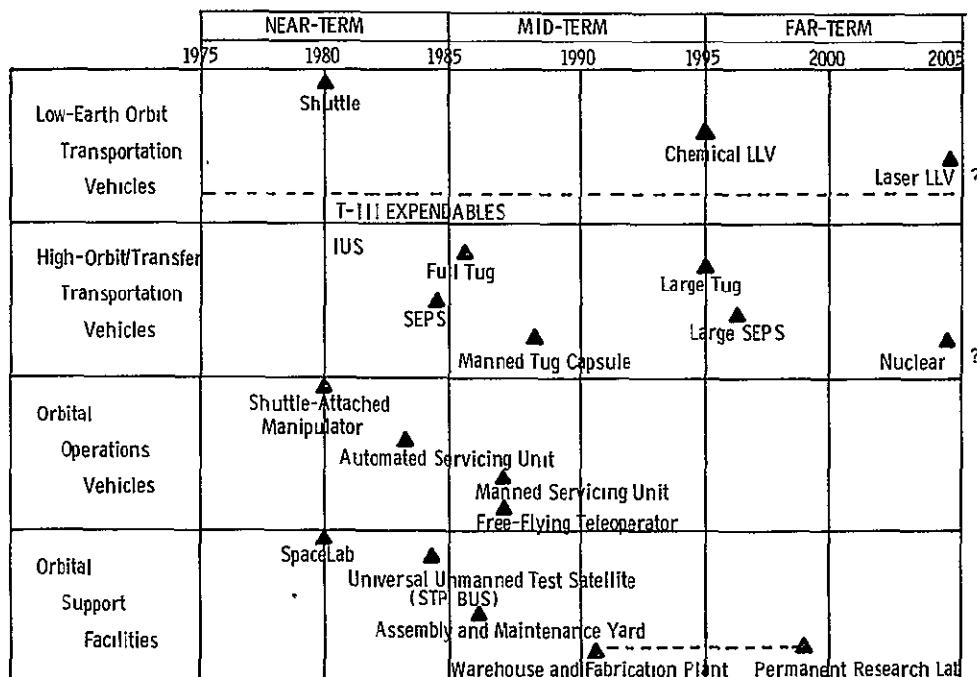


Figure 8-3. Common NASA-DoD Needs for Transportation and Support (1980-2000)

## 9. DEVELOPMENT PLANS

The purpose of this section is to present development plans for systems, building block elements, and technology which are essentially independent of the nature of the future world to be expected. The purpose of these development plans is twofold: firstly, to minimize the dependence of the support needs developed in the previous sections on subjective assumptions about the nature of the future; the second is to protect options for future development and deployment of almost any system without committing to such deployment at this time by identifying the technology which must be developed in order that those options be available at the appropriate time of need.

The needs for building block vehicles and facilities were derived from an assumed system mission model which was designed to incorporate representative systems in each major functional class. The support needs anticipated are shown in Figure 9-1 in the four major categories utilized for presentation of the mission opportunities and commonality data. Several trends are apparent from this graph:



**Figure 9-1. Anticipated Needs for Building Block Vehicles and Facilities**

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- a. Low Earth Orbit Transportation. The Space Shuttle is satisfactory for the missions through the early 1990's, with the need for a larger chemical lift vehicle not occurring until about 1995; a more efficient or very much larger capability than that not being required until considerably later. Throughout this time period there is anticipated a continuing need for an expendable booster of the Titan III-C/D class for some military missions which may not permit shuttle and tug operation profiles, manned operations, or revisit.
- b. High Orbit and Transfer Transportation. In addition to the Interim Upper Stage, a Full Capability Tug and the Solar Electric Propulsion Stage will be required, to be available operationally in the 1985 time period. A manned tug capsule may be required prior to 1990 should assembly and servicing of Geosynchronous Systems be needed. Larger versions of the tug and SEPS might not be required until the year 1995, and a nuclear stage not until considerably later.
- c. Orbital Operations Vehicles. The shuttle-attached manipulator, which is now a part of the baseline shuttle, is required (and will be available). An Automated Servicing Unit will probably be required in the early 1980's, and a Manned Servicing Unit or a Free-Flying Teleoperator in the late 1980's.
- d. Orbital Support Facilities. The Spacelab availability of 1980 should be augmented by an unmanned test satellite to replace the on-going DoD Space Test Program, and should be available in the 1984-1985 time period. An Assembly and Maintenance Yard, however defined, should be available in the late 1985-1987 time period to allow central servicing of vehicles. This is also the case for Warehouse and Fabrication Plants which are expected to be needed in the 1990 time period. The Spacelab would be expected to be augmented by or replaced with Permanently Orbiting Research Laboratories prior to the 2000 time period. These orbital facilities could grow in a modular manner to accommodate the expected increasing demands in the far term. This topic is expanded in Volume II.

It should be borne in mind that a "space station," of which several versions have been defined in the past and two are currently in Phase A study, could fill one or more of the functional roles required of the "orbital support facilities" of this study. However, the term "space station" has been avoided in this report in order that the conclusions not be unnecessarily restricted by any particular definition of a "space station."